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AUTHOR Cushing, Steven
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ABSTRACT

A study of the problems posed by the use of natural language in various aspects of aviation is presented. The study, part of a larger investigation of the feasibility of voice input/output interfaces for communication in aviation, looks at representative real examples of accidents and near misses resulting from language confusions and omissions. An intelligent voice interface is proposed for both real-time safety in the air traffic control/aircraft communications circuit and in the training of pilots and controllers. Such a device would monitor communications and filter out potential linguistic confusions, requiring clarification before conveying messages. The intelligent voice input component would consist of a voice word recognizer, to divide raw speech into meaningful elements, and a language filter to make interpretive decisions such as disambiguation and reference determination. The filter would use three components of natural language understanding: the lexicon, grammar, and knowledge base of air traffic control. The output component would be designed to check back with the speaker and provide required callouts and readbacks. (MSE)

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Language and Communication-related Problems of Aviation Safety[1]

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Steven Cushing

Department of Mathematics and Computer Science
Stonehill College, North Easton, MA 02357

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ABSTRACT

The research reported here is part of a broader, longer-term effort to investigate the feasibility of using voice input/output interfaces for various aspects of aviation.[2] Voice has a natural appeal as the preferred means of communication both among humans themselves and between humans and machines, since it is the form of communication that people find most convenient. However, the complexity and flexibility of natural language are problematic, because of the confusions and misunderstandings that can readily arise as a result of ambiguity, unclear reference, differences in punctuation or intonation, implicit inference, presupposition, and the like. In particular, language misunderstandings are revealed by data from NTSB and NASA/ASRS reports to have been a determining factor in aviation accidents and potential accidents. For example, the accident at Los Rodeos Airport, Tenerife, The Canary Islands, on March 27, 1977, resulted from a misunderstanding of the phrase ***at takeoff***, which was used by the flight crew to indicate that they were *in the* ***process*** *of taking off*, but was understood by the tower as meaning *at the takeoff* ***point***. The accident at John Wayne Orange County Airport, Santa Ana, California on February 17, 1981, resulted from a misunderstanding of the verb ***hold***, which can mean either *go around* or *continue doing what you're doing*, depending on the context. The accident that occurred at Miami International Airport, Miami, Florida, on December 29, 1972, resulted from a misunderstanding of the reference of the word ***things***, which the approach controller intended to refer to the aircraft's declining elevation, but which the crew took to refer to a nose gear problem that they had been preoccupied with, unaware of the declining elevation. These examples are representative of a wide range of accidents and near misses in which language misunderstandings or omissions have played a crucial role. A potential solution to this problem will be suggested.

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1. Introduction: Voice, Language, and Aviation

The research reported here is part of a broader, longer-term effort to investigate the feasibility of using voice input/output interfaces for various aspects of aviation. Voice has a natural appeal as the preferred means of communication both among humans themselves and between humans and machines, since it is the form of communication that people find most convenient. However, the complexity and flexibility of natural language are problematic, because of the confusions and misunderstandings to which they readily give rise. Some of these kinds of problems will be discussed and illustrated, in general terms, in Section 2. Representative real examples of accidents and near misses that have resulted from such problems will be discussed in Sections 3-5. A solution will be suggested, in outline, in Section 6.

2. General Problems of Natural Language Understanding

Problems can arise in natural language understanding as a result of such phenomena as ambiguity, uncertain reference, differences in punctuation or intonation, implicit inference, and presupposition. ***Ambiguity*** is illustrated by a sentence like (1), in which the noun phrase ***flying planes*** can mean either *the flying of planes*, *planes that are flying*, or, if ***flying*** is stressed, *planes that are* ***for*** *flying* (as opposed to some other kind — e.g., geometric or carpentry-related — of planes).

(1) Flying planes can be dangerous.

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Uncertain reference is illustrated by a sentence like (2), in which the pronoun ***it*** can be referring either to ***the state or experience of*** *being a pilot*, to ***the fact of his wife's*** *being a pilot* (he thinks she's a flight attendant), or to something else entirely (such as a burglary in which a pilot's hat is found unexpectedly at the scene of the crime).

(2) His wife is a pilot, but he doesn't know anything about it.

Problems of ***punctuation*** and ***intonation*** are illustrated by sentences and dialogues like (3) and (4), respectively, in which the presence or absence of an apostrophe or a difference in stress can drastically alter the sense of a statement.

(3) (a) The flight attendant stood by the door
and called the passengers' names as they arrived.

(b) The flight attendant stood by the door
and called the passengers names as they arrived.

(4) **That's** a good one!
What was that?!
Oh, that's **good** one, sir!

Implicit inference occurs in a sentence like (5), in which what the second clause says is entirely unrelated, explicitly, to what the first clause says but still somehow manages to undo its effect.

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(5) No doubt the passengers are honest,
but I wouldn't leave my wallet lying around.

Problems of ***presupposition*** are illustrated by a sentence like (6), in which **either** a ***yes*** or a ***no*** answer equally commits the responder to an implicit admission that the pilot **has**, in fact, been drinking.

(6) Is the pilot still hungover?

Only an **explicit denial** of the presupposition itself — "Just a minute! What do you mean? The pilot wasn't drinking!" — will suffice to counter the tacit admission.

3. *Accidents* that Have Resulted from Language *Confusions*

As amusing as examples like (1)-(6) may be, it turns out to be **not** so amusing that serious aviation accidents, in which many lives are lost, can be traced, in large part, to language problems of exactly these kinds. In this section, three representative examples will be cited to illustrate this fact.

3.1. Los Rodeos, Teneriffe,1977.

The accident at Los Rodeos Airport, Tenerife, The Canary Islands, on March 27, 1977, resulted, in large part, from a misunderstanding of the phrase ***at takeoff***, which was used by the flight crew to indicate that they were *in the* ***process*** *of taking off*, but was understood by the tower as meaning *at the*

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takeoff ***point*** [22,23]. This misunderstanding itself resulted, in turn, from a prior confusion as to exactly what clearance had been given. The subsequent collision with another aircraft that was still on the runway resulted in the loss of 583 lives, the worst accident in aviation history. A proper understanding of the cited phrase would have enabled the controller to advise action that could have prevented the collision.

3.2. John Wayne, Santa Ana, 1981.

The accident at John Wayne Orange County Airport, Santa Ana, California on February 17, 1981, resulted from a misunderstanding of the verb ***hold***, revealed in the dialogue in (7) [14].

(7)	**0134:13 Tower:**	Okay Air Cal **three thirty six, go around** three thirty six, **go around**.
	(0134:16 AC 336 Captain, *intra*-cockpit:	Can we **hold**, ask him if we can --- **hold**.)
	0134:18 Tower:	Air Cal **nine thirty one** if you can **just go ahead and hold** ---.
	0134:21 AC 336:	Can we **land** tower?
	0134:22 Tower:	Behind you Air Cal **nine thirty one just abort**.
	0134:25 Tower:	Air Cal three thirty six, please go around sir traffic is going to abort on the departure.

Does ***hold*** mean *go around* -- i.e., ***stop*** *what you're now doing* --, as it usually does in a landing situation, or does it mean *land* -- i.e., ***continue*** *what*

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you're now doing, as the 336 officer seems to interpret it at 0134:21 in response to the captain's intra-cockpit instruction? And, **whatever *hold*** might mean, there is bound to be confusion, from the **phonetic** similarities alone, in ***Air Cal*** *three* ***thirty*** *six* being told to *go* ***around*** at 0134:13 and ***Air Cal*** *nine* ***thirty*** *one* being told to *go* ***ahead*** at 0134:18, just five seconds later. These confusions resulted in Air California 336 landing with its gear retracted, having finally decided to go around, but too late actually to do so. This resulted in 34 injuries, 4 of them classified as serious, and the complete destruction of the aircraft by impact and post-impact fire.

3.3. Miami International, 1972.

The accident that occurred at Miami International Airport, Miami, Florida, on December 29, 1972, resulted from a misunderstanding of sentence (8), in which the approach controller used ***things*** to refer to the aircraft's apparent decline in elevation, as he had seen it indicated on radar, but which the crew took to refer to a nose gear problem that they had been preoccupied with, unaware of the decline in elevation precisely because of this preoccupation [11].

(8) How are things comin' along out there?

When the crew responded, "Okay," the controller concluded that the decline in elevation was under control, though, in fact, the crew had not a clue that the elevation was even a problem. The aircraft subsequently crashed into the Everglades, resulting in 101 deaths.

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4. *Accidents* that Have Resulted from Language *Omissions*

Another class of language-related accidents has occurred not because of **misunderstandings** of language, but from the **absence** of language, i.e., from people **not** saying what they were supposed to. Two examples will be cited here.

4.1. Monroe County, Rochester, 1978.

At Monroe County Airport, Rochester, New York, on July 9, 1978, "the aircraft overran the end of the runway,...crossed a drainage ditch and came to rest 728 ft past the end of the runway threshold" [12]. Damage to the aircraft was substantial, though there was no fire, and "... one passenger was injured seriously." The National Transportation Safety Board determined the probable cause of the accident to be "the captain's complete lack of awareness of airspeed, vertical speed, and aircraft performance," with "**the first officer's failure to provide required callouts** which might have alerted the captain to the airspeed and sink rate deviations" (emphasis added).

4.2. Portland International, 1978.

At Portland International Airport, Portland, Oregon, on December 28, 1978, an aircraft "crashed into a wooded populated area...during an approach to the ... airport," resulting in the complete destruction of the aircraft [13]. "Of the 181 passengers and 8 crew members aboard, 8 passengers, the flight engineer, and a flight attendant were killed and 21 passengers and 2 crewmembers were injured seriously." The National Transportation Safety Board determined the

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probable cause of the accident to be "the failure of the captain to monitor properly the aircraft's fuel state and to properly respond to the low fuel state and the crewmember's advisories regarding fuel state," a failure resulting from "preoccupation with a landing gear malfunction and preparations for a possible landing emergency." "Contributing to the accident was the failure of the other two flight crewmembers either to fully comprehend the criticality of the fuel state **or to successfully communicate their concern to the captain**" (emphasis added).

5. Language-related *Near-miss* Occurrences

The National Aeronautics and Space Administration's Aviation Safety Reporting System (NASA/ASRS) reports a wide range of near-miss incidents, many of which crucially involve linguistic misunderstandings or omissions. Since these are **self**-reports, submitted by pilots, controllers, flight attendants, and sometimes even passengers, all identifying information is eliminated before publication, in order to ensure the anonymity and confidentiality that is necessary for the system to work. The following four cases are typical.

5.1. *Heading* ➡ *Flight Level*

From a controller:

1: Controller clears Aircraft **A** to **descend** to **flight level 280**.

2: Controller clears Aircraft **B** to **climb** to **flight level 270**.

3: Controller issues Aircraft **A** a **heading** of **240**.

4: Pilot acknowledges with "**Roger two four zero**".

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5: Aircraft **A descends** through Aircraft **B**'s **altitude**.

6 Controller observes Aircraft **A** at altitude **27,200** and questions pilot.

7: Pilot claims he was **cleared to flight level 240** and he acknowledged it.

"A full readback by the pilot would have prevented the incident as his misunderstanding would have been noticed prior to descending below FL 280" [8].

5.2. *Vector* ➡ *Flight Level*

From a pilot:

1: Aircraft is **heading 300** degrees at **flight level 270**.

2: Controller gives aircraft a **vector** to **three one zero**.

3: First Officer acknowledges "**three one zero**" but **climbs** to it instead of **turning** to it.

4: Captain, **temporarily diverted**, notices aircraft climbing and corrects error.

Again, "a full readback would eliminate incidents like these" [8].

5.3. *To* ➡ *Two* (*Climb* vs. *Descend*)

From a pilot:

1: Departure Control gives the clearance "**Climb TWO five zero**".

2: Copilot **repeats** that clearance and dials **25,000** into the autopilot.

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3: Pilot notices traffic **1500** feet above and resets dial to **descend TO 5000**.

This incident took place "at a foreign airport" [10], where English may well have been a foreign language, though it is required by international law for aviation communications.

5.4. *Flight Level ➔ Airspeed*

From a crew member:

1: During climb Aircraft is cleared to **flight level 310**.

2: At about **flight level 260** Center Controller asks about Aircraft's **airspeed**.

3: Pilot answers "**315 knots**".

4: Controller replies "**Maintain 280**".

5: Pilot **answers "280 knots"**, **slows** to **280 knots,** and **continues climb** to **flight level 310**.

6 At about **flight level 295** Controller asks for Aircraft's **altitude** and pilot replies "**295**".

7: Controller says Aircraft was cleared only to **flight level 280**.

These examples are representative of a wide range of accidents and near misses in which language misunderstandings or omissions have played a crucial role. Though readbacks are potentially corrective in many such circumstances, they are, typically, simply not forthcoming. In the next section a solution to this problem is suggested and described in outline.

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6. A Solution: An Intelligent Voice Interface

The examples in Sections 3-5 strongly suggest the development of an ***intelligent voice interface*** for aviation communications, i.e., a device that would monitor communications and filter out potential linguistic confusions of the illustrated kinds, checking with the speaker for clarification before conveying messages and monitoring the aircraft's state, providing needed callouts automatically. Such a system would be valuable on-line, as **a safety device in real-time**, but would be useful also as **a training device**, developing an awareness in both pilots and controllers of the kinds of linguistic constructions they ought to avoid, while conditioning them, to some extent, to do so.

The **general** structure of such a system, as it would function in the air–traffic–control/aircraft communication circuit, is shown in **Figure 1**. Each speaker speaks, as usual, into a microphone, but the message is filtered through an ***intelligent voice input component*** and inspected for linguistic problems before being conveyed; the system checks back with the speaker via an ***intelligent voice output component***, when explicit clarification is needed. The intelligent voice output component serves the further function, as well, of guaranteeing that required callouts and readbacks are provided by providing them itself when necessary. The intelligent voice input component also seems to have potential, incidentally, for the mediation of voice communications **between humans and machines**, as outlined in **Figure 2**.

The intelligent voice input component consists of two subcomponents, the ***voice word recognizer***, in which raw speech is deciphered into meaningful

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linguistic patterns, and the ***language filter***, in which disambiguation, reference determination, and other interpretive decisions are made, and it feeds its results into the intelligent voice output component, as shown in **Figure 3**. The language filter makes crucial use of the three components of natural language understanding shown in **Figure 4**, the lexicon and grammar of the language in question and the knowledge base that is available to the understander.

The ***lexicon*** contains the vocabulary of the language, consisting of one or more entries for each word, specifying its meanings and its grammatical peculiarities. The ***grammar*** is a specification of the general syntactic patterns of the language, the rules and/or principles that determine the relative grammaticality of arbitrary strings of words. A lexicon can be structured as a list, a network, or some more complicated algebraic structure [1,2]. A grammar can also be structured to varying degrees of complexity, containing rules and/or principles of different possible forms [19]. The content of the lexicon and grammar are derived, in large part, from actual examples of aircraft/air traffic control dialogue, such as the accident-related examples discussed in Sections 3–5.

The ***knowledge base*** contains the extra–linguistic real–world, pragmatic, and domain–specific knowledge that underlies implicit inference, that can be crucial in disambiguating sentences with more than one meaning, and that can be useful in determining the reference of pronouns in unclear cases. The knowledge base includes information concerning the actual flight and air traffic control environment, to the extent that this is needed to clarify linguistic confusions. More detailed working out of these components and their inter-relationships is beyond the scope of this paper.

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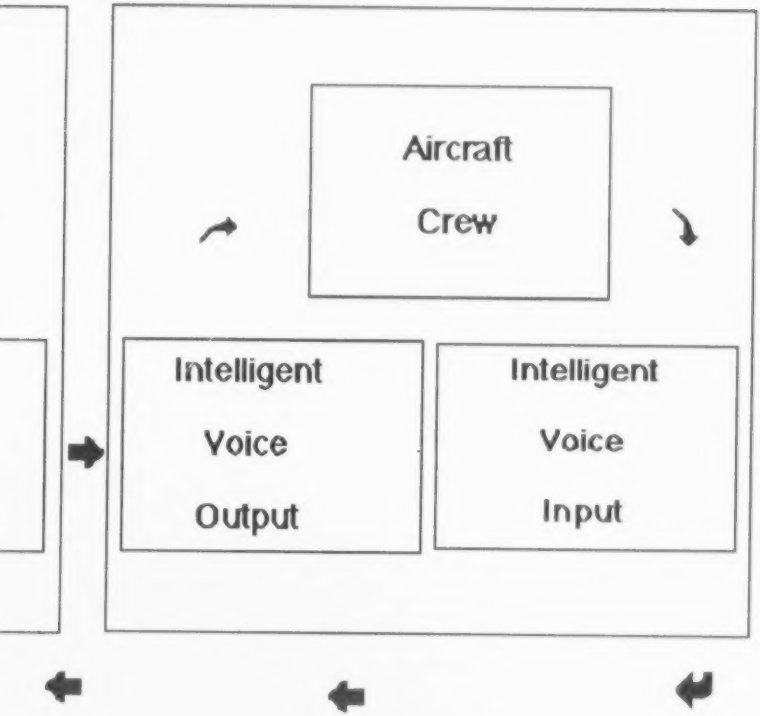
Figure 1:

ELLIGENT VOICE I/O NETWORK

R TRAFFIC CONTROL



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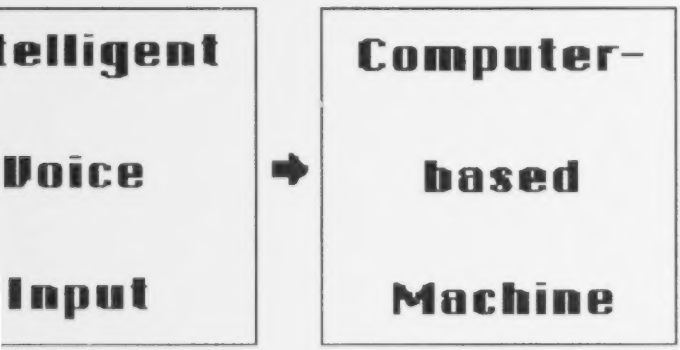

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The Subcomponents of the Intelligent Voice Input Component

Figure 3:

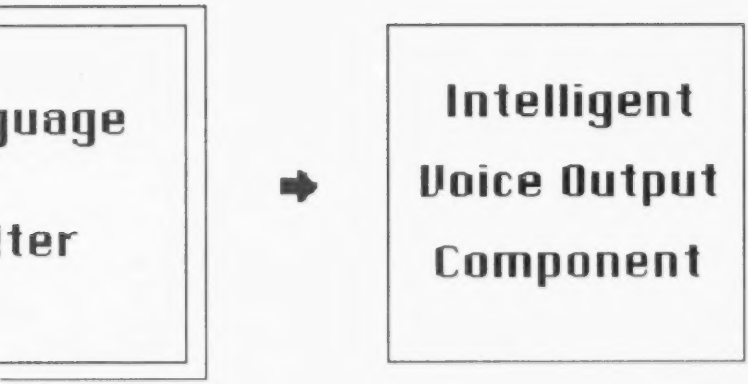
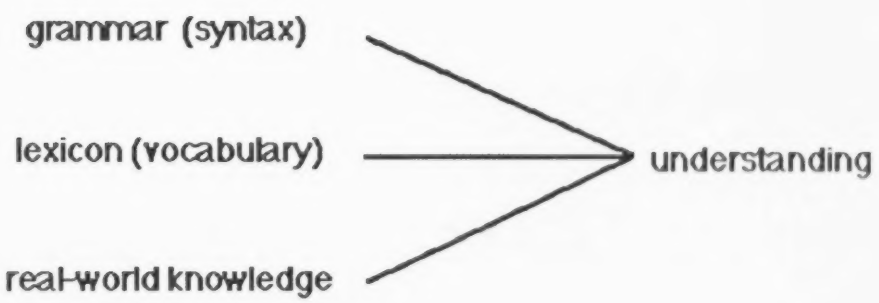


Figure 4:

Components of Language Understanding:



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